CHAPTER 5

HUMAN-MADE STRUCTURES

5-1. Bulkheads, Seawalls, and Revetments.

a. General.

(1) Where beaches and dunes protect shore developments, additional protective works may not be required. However, when natural forces do create erosion, storm waves may overtop the beach and damage backshore structures. Human-made protective structures may then be constructed or relocated to provide protection. In general, measures designed to stabilize the shore attempt to either harden the shore to enhance resistance to wave action, prevent waves from reaching the shore (or harbor), prevent waves from overtopping an area, or attempt to retard the longshore transport of littoral drift. In this chapter, three types of human-made shore protection structures will be discussed:

(a) Bulkheads, seawalls, and revetments.

(b) Jetties and breakwaters.

(c) Groins.

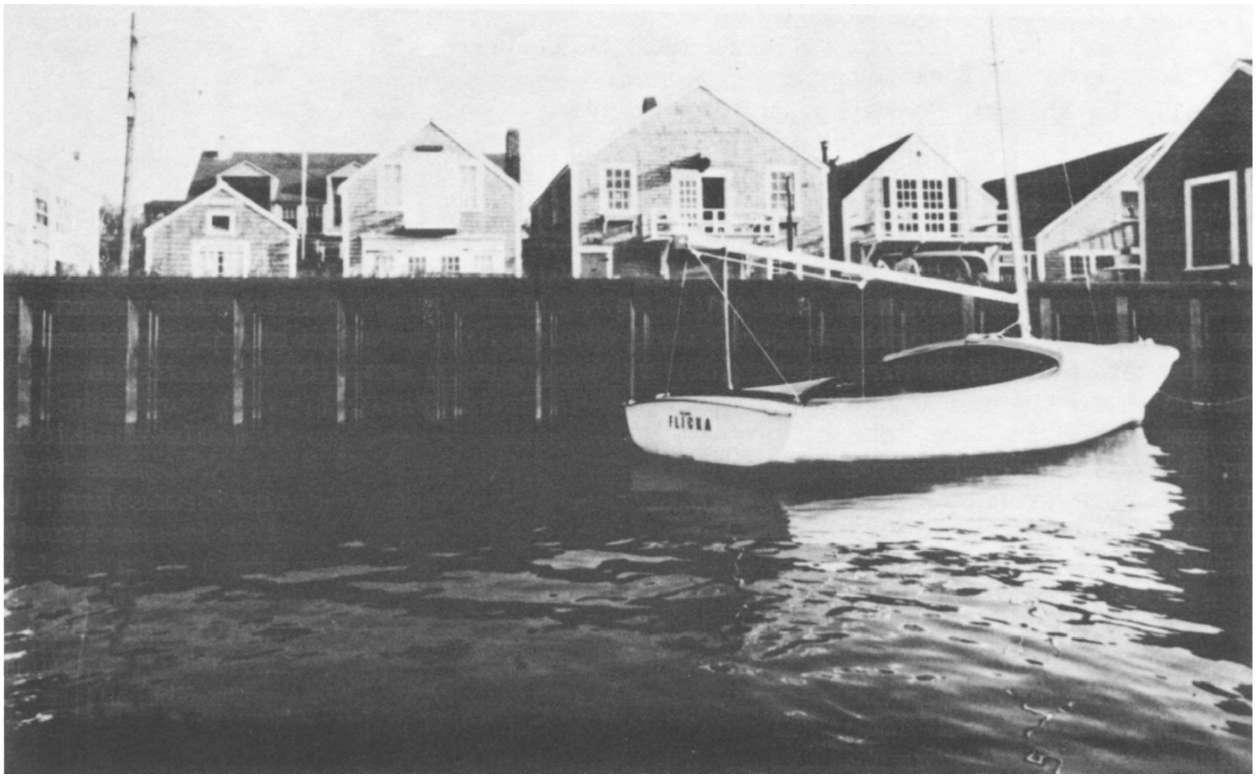
(2) Onshore structures, termed bulkheads, seawalls, and revetments, provide protection, based on their use and design, for the upper beach which fronts backshore development or erodible bluffs. Shorefront owners have resorted to shore armoring by wave-resistant walls of various types when justified by the economic or aesthetic value of the property to be protected.

b. Role in Shore Protection.

(1) Onshore structures are intended to protect the shore by reducing the rate of change in the shoreline. They slow the rate of change by protecting the shore from wave impact or by preventing overwash.

(2) Bulkheads and seawalls are similar in design with slightly differing purposes. Bulkheads are primarily soil-retaining structures which are designed to also resist wave attack (Figure 5-1). Conversely, seawalls are principally structures designed to resist wave attack, but also may retain some soil to assist in resisting wave forces. The land behind seawalls is usually a recent fill area. Bulkheads and seawalls may be built of many materials including steel, timber or concrete piling, gabions, or rubble-mound structures.

(3) For ocean-exposed locations vertical bulkheads alone do not provide a long-term solution because of foreshore erosion, toe scour, and flanking. Unless combined with other types of protection, the bulkhead must be enlarged into a massive seawall capable of withstanding the direct onslaught of the waves (Figure 5-2). Seawalls may have vertical, curved,



Nantucket Island, Massachusetts (1972)
(photo, courtesy of U.S. Steel)

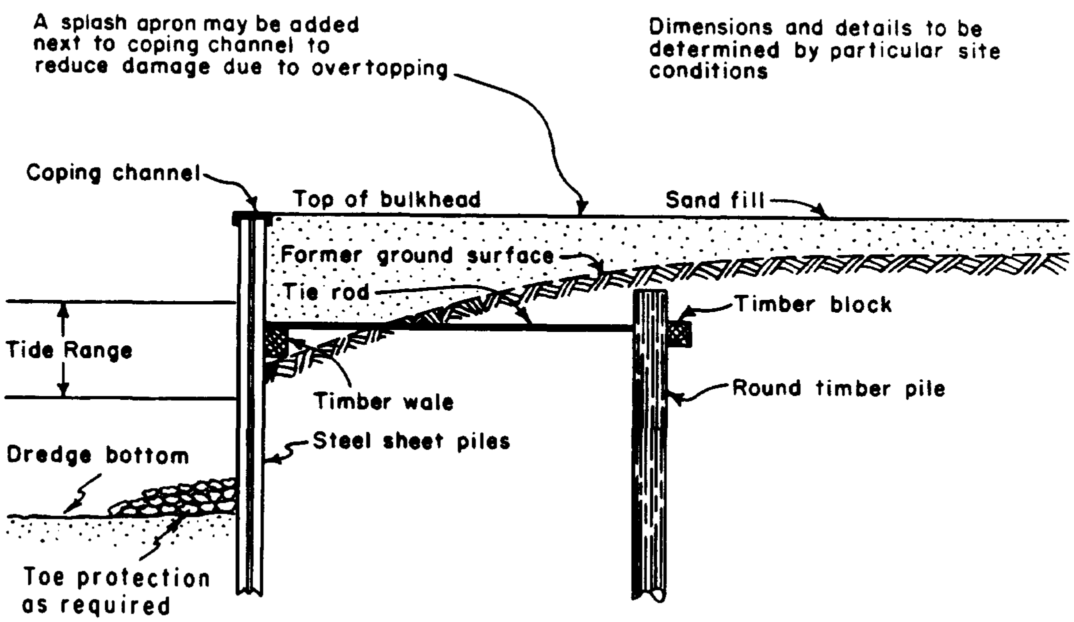


Figure 5—1. Steel sheet pile bulkhead

stepped, or sloping faces. Although seawalls protect the upland, they often create a local problem. Downward forces of water, produced by waves striking the wall, can rapidly remove sand from in front of the wall. A stone apron is often necessary to prevent excessive scouring and undermining.

(4) A revetment armors the existing slope face of a dune or embankment. It is usually composed of one or more layers of quarry stone or precast concrete armor units, with a filter layer overlaying a graded soil slope (Figure 5-3). Revetments are of little benefit if placed at the toe of a marginally stable slope since they are usually only a protective armor and not a retaining structure. Because the sloping face of the quarrystone revetment is a good energy dissipater, revetments have a less adverse effect on the beach in front of them than a smooth-faced vertical bulkhead.

c. Physical Considerations. The littoral system at the site of a structure is always moving toward a state of dynamic equilibrium where the ability of waves, currents, and winds to move sediment is matched by the available supply of littoral materials. When there is a deficiency of material moving within a system, the tendency will be for erosion at some location to supply the required material. Once a structure has been built along a shoreline, the land behind it will no longer be vulnerable to erosion (assuming proper design of the structure), and the contribution of littoral material to the system will be diminished along the affected shoreline. The contribution formerly made by the area must now be supplied by the adjoining areas. Therefore, though the structure provides a measure of stability to a portion of the shoreline, it may indirectly increase the rate of erosion along other reaches of the shoreline (Bellis et al 1975, Carstea et al. 197 5a-b, Georgia Department of Natural Resources 1975, Herbich and Schiller 1976, Pallet and Dobbie 1969, US Army Engineer District, Baltimore 1975, Mulvihill et al. 1980). In addition, some structures such as bulkheads may cause increased wave reflection and turbulence with a subsequent loss of fronting beach. Smooth, vertical structures will have the greatest impact on the beach and nearshore sediment loss.

d. Water Quality Considerations.

(1) The impacts of onshore structures on water quality result from increased suspended solids during construction and altered circulation patterns produced by the structure itself.

(2) Construction of onshore structures may require excavation, backfilling, pile driving, and material transport. These activities can result in increased suspended solid loads within the adjoining water body (Boberschmidt et al. 1976, Carstea et al. 197 5a-b and 1976, Environmental Quality Laboratory, Inc. 1977, US Army Engineer District, Baltimore 1975, Virginia Institute of Marine Science 1976, Mulvihill et al. 1980). The increased concentration of suspended solids is generally confined to the immediate vicinity of the construction activity and dissipated rapidly at the completion of the operation. Although these are generally short-term impacts, construction

Galveston, Texas (1971)

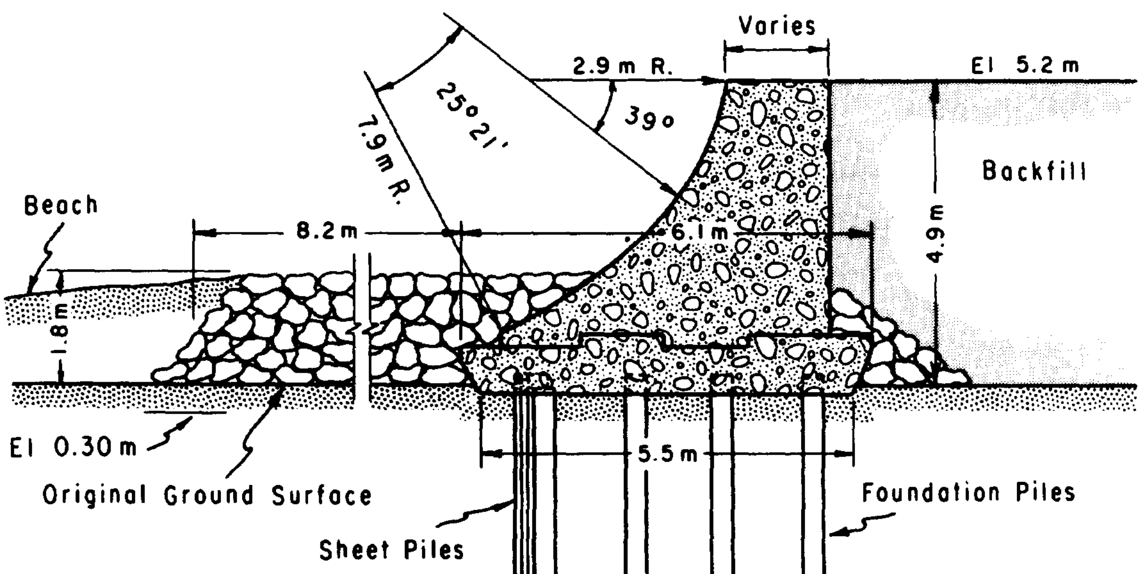


Figure 5-2. Concrete curved-face seawall

Chesapeake Bay, Maryland (1972)

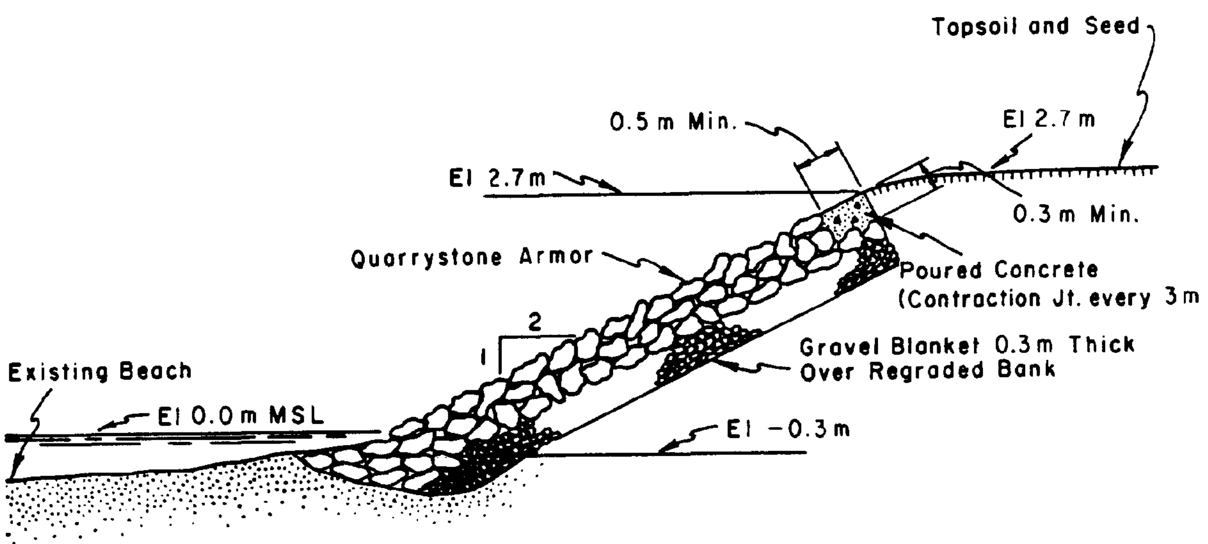


Figure 5-3. Quarrystone revetment

activities should be designed to minimize generation of suspended solids, for example, by the use of silt curtains in low-energy areas. See paragraph 4-11(1) (b) for a discussion of the limitation of silt curtains.

(3) Structures can influence water quality by altering circulation patterns. Modification in circulation can result in changes in the spatial distribution of water quality constituents, differences in the flushing rates of potential contaminants, and changes in the scour patterns and deposition of sediments (Bauer 1975, Carstea et al. 1975a-b, Georgia Department of Natural Resources 1975, Mulvihill et al. 1980). Environmental assessment of the effects on circulation should initially emphasize fundamental parameters such as salinity, temperature, and current velocity. If minimal changes occur in these parameters, then it can be assumed that the chemical characteristics of the system will not be significantly modified. Prediction of changes in circulation and its effect on the physical parameters can be achieved through comparison with existing projects, physical model studies, and numerical simulation (see Appendix B).

e. Biological Considerations. A wide variety of living resources is present in coastal shore protection project areas and includes species of commercial, recreational, and aesthetic importance. Because shore protection projects exist in arctic, temperate, and tropical climates, biological impacts will generally be highly site-specific and depend upon the nature and setting of the project.

(1) Short-term impacts. Short-term biological impacts are usually associated with the actual construction phase of the project. The actual time is typically short (measured in days and weeks) and therefore can be scheduled to minimize negative impacts. Transportation of material to the site, preparation and construction using heavy equipment, and backfilling and grading will cause temporary air and noise pollution close to the site. Nesting, resting, or feeding waterfowl, fish, and other wildlife may be disrupted. Projects should be timed, where possible, to avoid waterfowl and turtle nesting periods and fish spawning periods. Construction will also temporarily reduce water quality, generally by suspending sediments and generating turbidity. The environmental impacts on the benthic communities resulting from suspended solids in the water around shore protection construction are for the most part minor. Such impacts are particularly true in the surf zone on open coast beaches where rapid natural changes and disturbances are normal and where survival of the benthic community requires great adaptability. On rapidly eroding banks, construction impacts on suspended solids may be minimal when compared to the natural condition. However, sites with a high percentage of fine material and in proximity to seagrass beds or coral reefs (habitats sensitive to turbidity and siltation) will require special consideration and usually precautions such as silt curtains, where feasible. Temporary turbidity will also interfere with respiration and feeding, particularly of nonmotile bottom dwellers. Most motile organisms will avoid or flee the disturbed area.

(2) Long-term impacts.

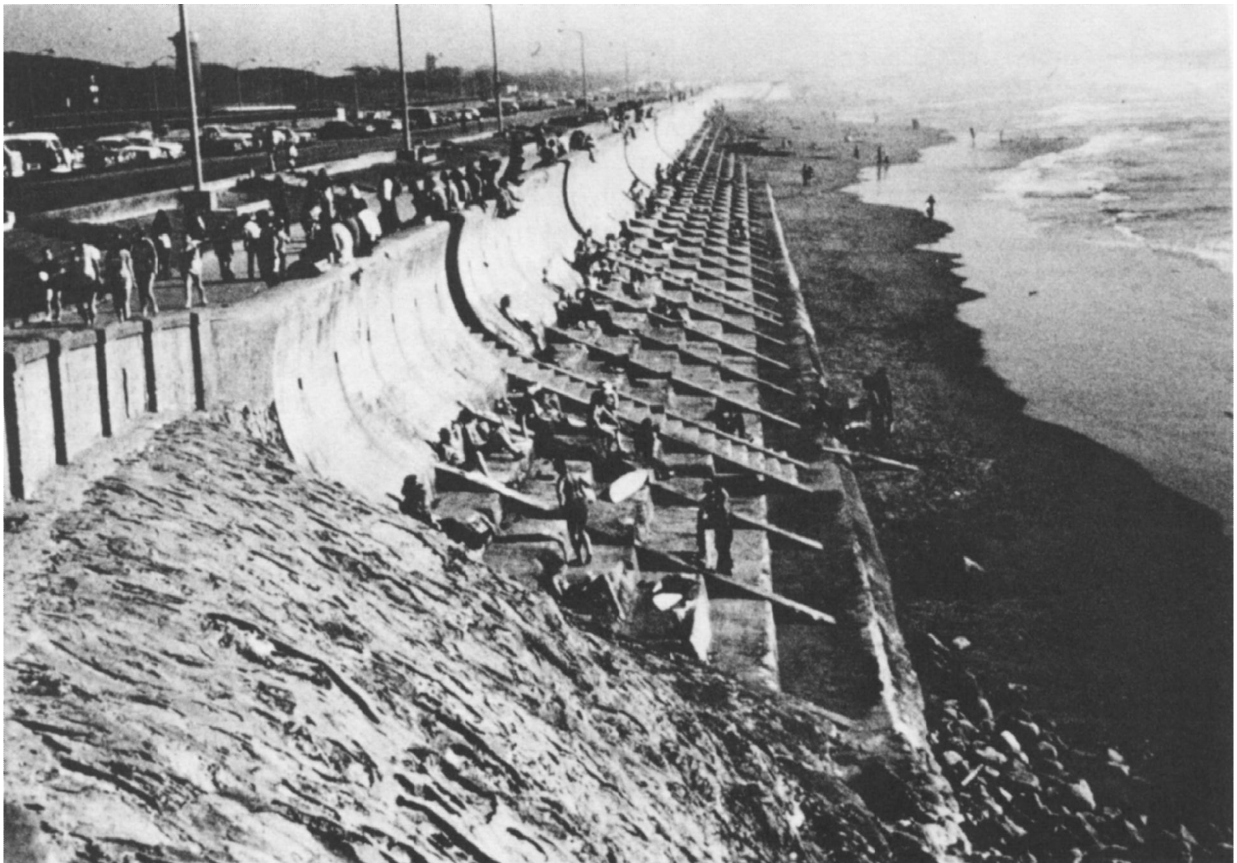
(a) Long-term effects vary considerably depending upon the location, design, and material used in the structures. Placement of coastal shore protection structures requires an initial disturbance of the benthic substrate, but it results in the formation of a new substrate composed of structural material. In many locations the placement of these structures provides new habitat not available otherwise. The biological productivity of the area to be displaced is also important. The impact of a vertical steel sheet bulkhead located at mean low water in a coastal marsh (highly productive habitat) will be considerably different from a rubble-reveted bank in an industrialized harbor.

(b) Vertical structures in particular may accelerate erosion of the foreshore and create unsuitable habitat for many bottom species in front of the structure as the result of increased turbulence and scour from reflected wave energy. Bulkheads and revetments can reduce the area of the intertidal zone and eliminate the important beach or marsh habitat between the aquatic and upland environment. The result can be a loss of spawning, nesting, breeding, feeding, and nursery habitat for some species. On the other hand, rubble toe protection or a riprap revetment extending down into the water at a sloping angle will help dissipate wave energy and will provide hard-bottom habitat for many desirable species.

f. Recreational Considerations. Bulkheads can severely limit recreational use of the shoreline (Brater 1954, Mulvihill et al. 1980). In particular, they restrict public access to the water (Coastal Plains Center for Marine Development Service 1973, Snow 1973, Mulvihill et al. 1980). Revetments also hamper public access to the water for water contact activities. Seawalls are frequently designed to permit public access and to enhance beach usage (Figure 5-4). However, where beach erosion persists in the vicinity of the above onshore structures, the usable portion of the recreational beach is usually diminished.

g. Aesthetic Considerations. The transition between land and water on a natural shoreline is either gradually sloping, consisting of a beach or marsh, or is sharply defined by a bank or scarp. Onshore structures are more similar to the latter in that they often represent an abrupt visual change. Bulkheads and revetments can sometimes be designed to blend in with the surrounding shoreline. For example, their natural appearance can be enhanced with the use of vegetation. The use of unusual construction materials such as junk cars, tires, or recycled construction debris would produce the greatest negative aesthetic impacts. Because seawalls are frequently large concrete structures and are usually located in densely populated areas, particular attention should be paid to their visual impact. The design of a structure should be visually attractive as well as functionally sound.

h. Cultural Resource Considerations. By reducing erosion rates, onshore structures will generally preserve onsite cultural resources. However, this local protection can potentially increase the rate of erosion on adjacent



San Francisco, California (June 1974)

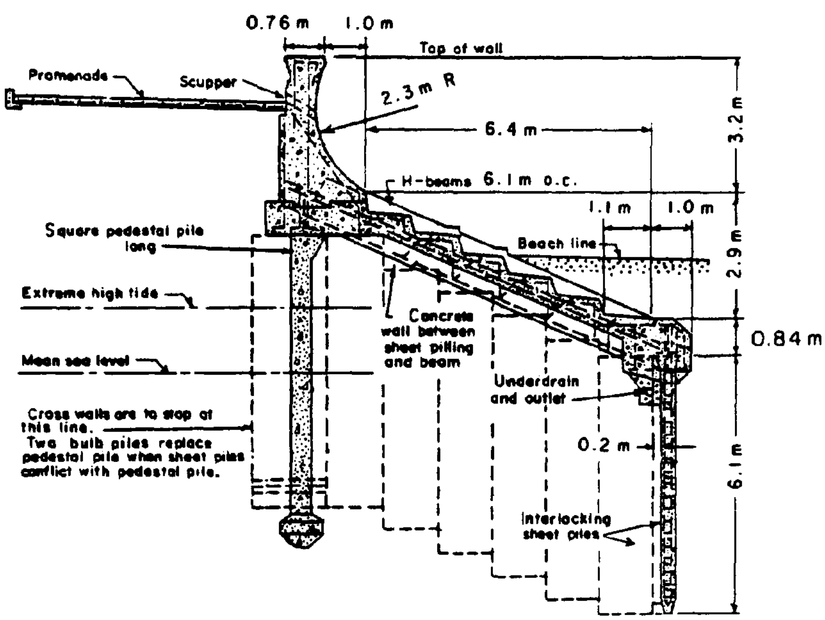


Figure 5-4. Concrete combination stepped- and curved-face seawall with public access points

shorelines. For this reason, cultural resources in the adjacent impact area must also be evaluated and projects designed so that erosion of adjacent areas is avoided.

i. Environmental Summary.

(1) Environmental design. Table 5-1 summarized potential design modifications that can be made to revetments, seawalls, and bulkhead projects in order to improve their environmental characteristics.

(2) Environmental assessment.

(a) Short-term impacts. Construction activities associated with onshore structures may include excavation, backfilling, and pile driving using both heavy equipment and hand labor. The impacts of this construction will be similar to the impacts associated with other land-based construction activities: vegetation damage, noise and air pollution, visual clutter, and other temporary impacts. Because this construction takes place on the shoreline, however, other impacts not usually associated with land-based construction activities are also possible. One of the short-term impacts of shoreline construction is the increased levels of suspended sediments in nearshore waters which accompany this disturbance. Suspended sediments and siltation can impact benthic communities and to a lesser extent life forms in the water column. Because of the local nature and short duration of this impact, it will be a primary consideration only in projects which are near sensitive habitats such as coral reefs and seagrass beds.

(b) Long-term impacts. The primary long-term impacts of onshore structures are associated with their effect on shore processes. Though these structures abate local erosion, they may indirectly accelerate erosion in adjacent shoreline areas. This accelerated erosion will be an important concern if potentially affected areas contain marsh vegetation, riparian vegetation, or other productive habitats. Wave reflection from exposed onshore structures may also produce deepening of the nearshore zone. Such losses may have recreational impacts and will alter biological habitats. Direct impacts of onshore structures include displacement of onsite habitats, modified public access, and aesthetic alterations.

5-2. Jetties and Breakwaters.

a. General.

(1) The distinction between jetties and breakwaters can be vague in that these structures are similar in many aspects of design and materials. They primarily differ with respect to function. Jetties are structures built at the mouths of rivers, estuaries, or coastal inlets to stabilize the position and prevent or reduce shoaling of entrance channels. A secondary function of a jetty is to protect an entrance channel from severe wave action or cross-currents, thereby improving navigational safety between harbors and deep water. Also, jetty construction can result in stabilization of the location

TABLE 5-1

Environmental Design Considerations for Revetments
Seawalls, and Bulkheads

Factor	Design Consideration	Environmental Benefit
Location	Site structure above mean high water	Allows intertidal zone to remain
		Allows shoreline vegetation to remain
		Does not interfere with littoral drift
	Avoid wetland sites, spawning beds, shore-bird and turtle nesting beaches, bird feeding and resting areas	
	Avoid nearby coral reefs and seagrass beds	Resource conservation
	Avoid archaeological sites	Preservation of historical information and features
Construction material	Rubble or riprap	Usually most desirable, natural, and durable
		Most reef-like surface area
	Treated wood and smooth concrete	Intermediate desirability and less surface area
	Steel sheet pile	Least desirable, least col-onizable surface
	Armor stone, largest cost-effective	More stabile physical habitat
		More size diversity of openings

(Continued)

TABLE 5-1 (Concluded)

Factor	Design Consideration	Environmental Benefit
Design	Riprap or stair-step revetments on a slope of 45 degrees or less when structure is partially submerged	Dissipates wave energy, more habitat for fish and reef fish
	Toe protection on structures below mean low water	More diverse habitat, reef-like properties, dissipates wave energy on bottom
	Sloping structures that are partially submerged	Reduce wave reflection Less disturbance of intertidal habitat due to scour Less disturbance of fish nursery habitat
	Natural contours and lack of sharp angles	Aesthetically pleasing Less debris capture Reduces chance for rip current formation

of an inlet on a barrier beach coastline. In contrast, the primary function of a breakwater is to protect a harbor, water basin, or shoreline from destructive wave forces. Thus, breakwaters provide calm waters for safe anchorages, moorings, access points, and a host of other water resource uses. Some breakwaters may also serve to create sediment traps in the nearshore zone.

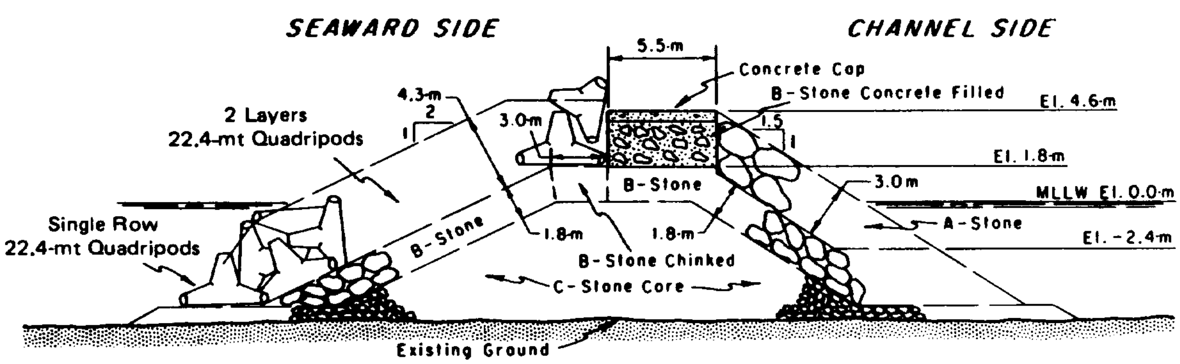
(2) There are no truly "typical" designs for jetty or breakwater structures. The multiplicity of physical, logistical, and economic factors considered during the planning, design, and construction phases ensure that each project will be unique. For example, the linear dimensions of a jetty structure will vary greatly from project to project, because the seaward extent of a jetty is determined largely by the distance offshore required to reach the design depth of the adjacent channel entrance. Physical factors, important from an environmental standpoint, include geomorphology of the project site, bottom topography, wave climate, sediment transport rates, and tide and current regimes, among others.

(3) Selection of construction materials has numerous alternatives, although jetties and breakwaters on open coastlines are predominantly rubble-mound structures. Other types of materials include vertical wood pile, steel sheet pile, caissons, sandbags, and, particularly in the Great Lakes, timber, steel, or concrete cribs. Rubble-mound structures consist of underlying layers of randomly shaped and placed stones that are overlaid by an armor (cover) layer of selectively sized stones or prefabricated concrete forms (Figure 5-5). Lateral toe-to-toe dimensions of rubble-mound structures, as well as the slope angles of their lateral faces, vary among projects based on design criteria for site-specific wave climates.

(4) Jetty or breakwater configurations follow basic patterns, but also demonstrate considerable variation to adapt to individual project conditions. Jetties generally extend seaward from the shore in a perpendicular fashion, but the actual angles vary from project to project. Updrift jetties may incorporate a weir section (submerged during some portion of the local tidal cycle) to allow littoral sand movement across the jetty and into a deposition basin (Figure 5-6). Sand bypassing can then be accomplished by periodic dredging of the basin. Breakwater configurations are somewhat more diverse than those for jetties, reflecting wider functional uses. Breakwaters can be categorized as either shore-connected or offshore (detached), and as either fixed or floating. Commonly the landward portion of a shore-connected breakwater lies perpendicular to the shoreline, and the seaward extension lies more or less parallel to the shore. Fixed breakwaters are constructed of materials placed on the bottom substrate, whereas floating breakwaters are buoyant structures held in position by anchors and tethers. Fixed breakwaters may be emergent or partially or totally submerged especially in the case of offshore designs.

b. Role in Shore Protection. Jetties and breakwaters are built to serve "stabilization" and "protection" functions. This fact infers that the

Santa Cruz, California (Mar. 1967)



A - Stone Avg. 9.2-mt, Min. 6.1-mt
B - Stone 50% > 2.8-mt, Min. 1.8-mt
C - Stone 1.8-mt to 0.1m 50% > 224-kg

Figure 5-5. Quadripod and rubble-mound breakwater

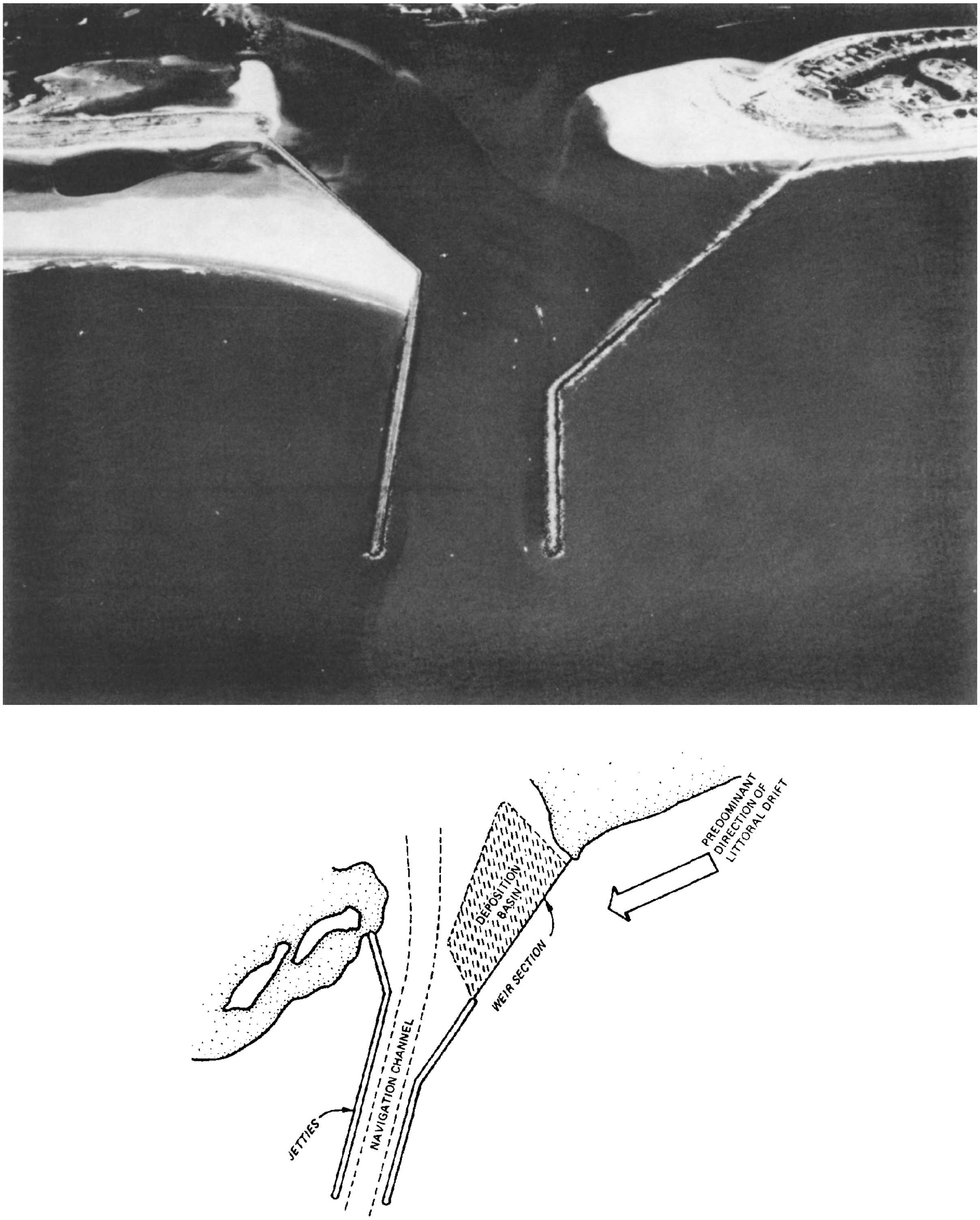


Figure 5-6. Sand bypassing, Murrells Inlet, South Carolina

environments in which they are built are characteristically dynamic and moderately to highly energetic.

(1) Jetties.

(a) Jetties are structures used at inlets to stabilize the position of the navigation channel, to shield vessels from wave forces, and to control the movement of sand along the adjacent beaches so as to minimize the movement of sand into the channel. The sand transported into an inlet will interfere with navigation depth. Because of the longshore transport reversals common at many sites, jetties are often required on both sides of the inlet to achieve complete channel protection. Jetties are built from a variety of materials, e.g., timber, steel, concrete, and quarrystone. Most of the larger structures are of rubble-mound construction with quarrystone armor and a core of less permeable material to prevent sand passing through. It is the impoundment of sand at the updrift jetty which creates the major physical impact. When fully developed, the impounded sand extends well updrift on the beach and outward toward the tip of the jetty.

(b) The jetty's major physical impact is the erosion of the downdrift beach. Before the installation of a jetty, nature supplies sand by intermittently transporting it across the inlet along the outer bar. The reduction or cessation of this sand transport due to the presence of a jetty leaves the downdrift beach with an inadequate natural supply of sand to replace that carried away by littoral currents.

(c) To minimize the downdrift erosion, some projects provide for periodically dredging the sand impounded by the updrift jetty and pumping it through a pipeline (bypassing the inlet) to the downdrift eroding beach. This pumping provides for nourishment of the downdrift beach and also reduces shoaling of the entrance channel. If the sand impounded at the updrift jetty extends to the head or seaward end of the jetty, sand will move around the jetty and into the channel causing a navigation hazard. Therefore, the purpose of sand bypassing is not only to reduce downdrift erosion, but also to help maintain a safe navigation channel.

(d) One design alternative for sand bypassing involves a low section or weir in the updrift jetty over which sand moves into a sheltered predredged, deposition basin. By dredging the basin periodically, channel shoaling is reduced or eliminated. The dredged material is periodically pumped across the navigation channel (inlet) to provide nourishment for the downdrift shore. A weir jetty of this type is shown in Figure 5-6. Environmental considerations of beach nourishment have been discussed in Chapter 4.

(2) Breakwaters.

(a) Breakwaters are wave energy barriers designed to protect any landform or water area behind them from the direct assault of waves. However, because of the higher cost of these offshore structures as compared to onshore structures (e.g. seawalls), breakwaters have been mainly used for harbor protection and navigational purposes. In recent years, shore-parallel, detached, segmented breakwaters have been used for shore protection structures.

(b) Breakwaters have both beneficial and detrimental effects on the shore. All breakwaters reduce or eliminate wave action in the lee (shadow). However, whether they are offshore, detached, or shore-connected structures, the reduction or elimination of wave action also reduces the longshore transport in the shadow. For offshore breakwaters, reducing the wave action leads to a sand accretion in the lee of the breakwater in the form of a cuspate sandbar (called a tombolo when a complete connection is made between the original beach and structure), which grows from the shore toward the structure.

(c) Shore-connected breakwaters provide protection to harbors from wave action and have the advantage of a shore arm to facilitate construction and maintenance of the structure.

(d) At a harbor breakwater, the longshore movement of sand generally can be restored by pumping sand from the side where sand accumulates through a pipeline to the eroded downdrift side.

(e) Offshore breakwaters have also been used in conjunction with navigation structures to control channel shoaling. If the offshore breakwater is placed immediately updrift from a navigation opening, the structure impounds sand in its lee, prevents it from entering the navigation channel, and affords shelter for a floating dredge plant to pump out the impounded material across the channel to the downdrift beach.

(f) While breakwaters have been built of everything from sunken ships to large fabric bags filled with concrete, the primary material in the United States is a rubble-mound section with armor stone encasing underlayers and core material. Some European and Japanese breakwaters use a submerged mound foundation in deeper water topped with concrete superstructure, thereby reducing the width and overall quantity of fill material necessary for harbor protection.

c. Physical Considerations.

(1) Jetty or breakwater construction is invariably accompanied by localized changes in the hydrodynamic regime, creating new hydraulic and wave energy conditions. The initial disruption of the established dynamic equilibrium will be followed by a trend toward a new set of equilibrium conditions. Rapid dynamic alterations in the physical environment may occur in the short-term time sale as the shore processes respond to the influence of the new structures. Slower, more gradual, and perhaps more subtle changes may occur over the long term.

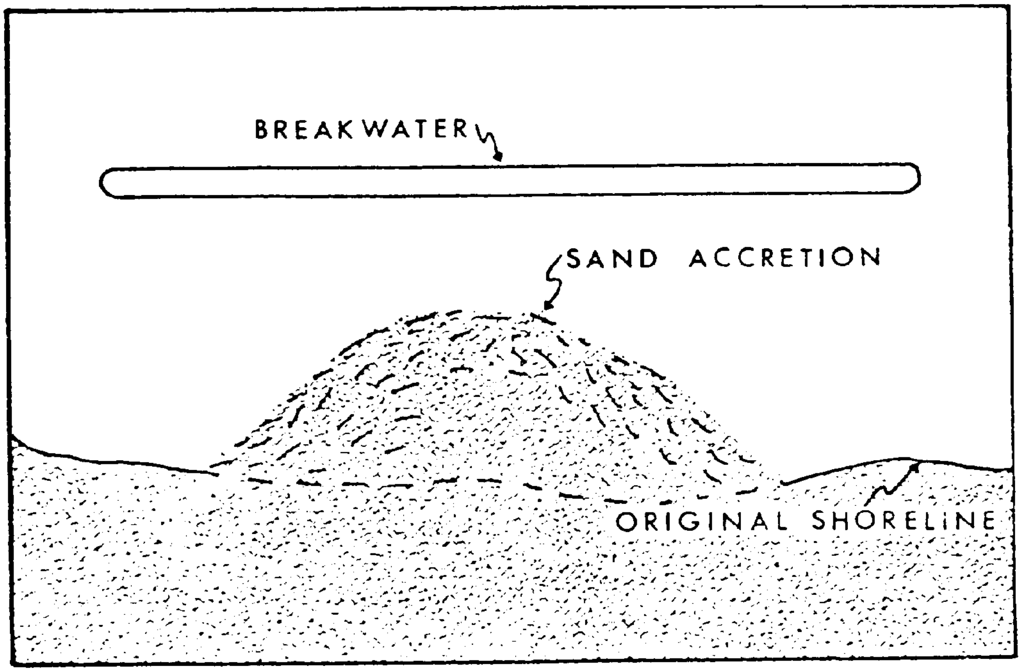
(2) In light of the dynamic character of shore processes, assessment of the effects of coastal engineering projects on shorelines is a difficult task.

Shoreline changes induced by the presence of a structure may be masked by wide annual or seasonal fluctuations in natural physical processes. Several events, however, can be predicted in response to jetty or breakwater construction with reasonable certainty. For example, by creating wave-sheltered areas, construction will result in changes in the erosional and depositional patterns along adjacent beaches, both inshore and offshore. A jetty or shore-connected breakwater will form a barrier to longshore transport if the structure extends seaward beyond the surf zone. In the particular case of a jettied inlet, sediment will tend to accrete on the seaward side (opposite the entrance channel) of the updrift jetty. Spatial extent of the ensuing shoreline alteration will depend on the structure’s effectiveness as a sediment trap, which is a function of its orientation to the inlet and to the prevailing wave climate. Updrift accretion of sediments will continue until the sink area is filled to capacity and the readjusted shoreline deflects longshore transport past the seaward terminus of the jetty. The volume of sediment trapped by the structure represents material removed from the natural sand bypassing process. Consequently, the downdrift shoreline will be deprived of this sediment and become subject to erosion. In circumstances where waves are refracted around the structures in a proper manner, accretion can occur along the seaward side of a downdrift jetty. Reflection of waves from a jetty may also cause erosion of adjacent shorelines. However, erosion further down the shoreline is not precluded. Planning for adequate sand bypassing is, in view of the above considerations, a critical requirement of coastal structure construction.

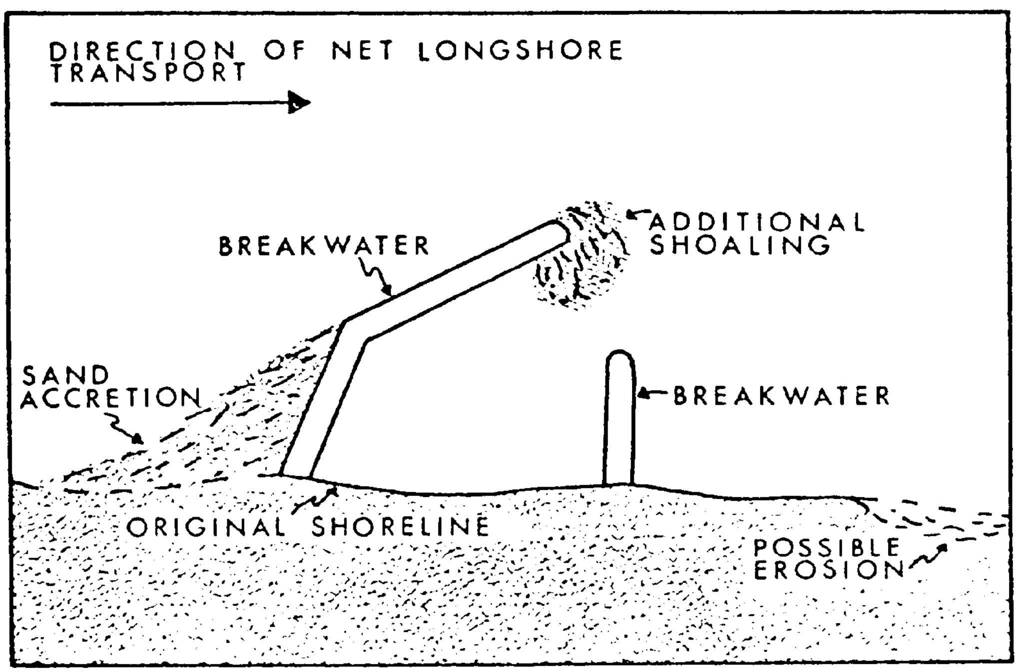
(3) Erosion at jetty project sites will not necessarily be limited to downdrift shorelines. Jetties redirect the course of the main ebb channel and confine ebb flows through an inlet such that current velocities are increased. An enhancement of ebb jet flows will result in displacement of sediments from between the jetties in a seaward direction to deeper waters. Also, sediments comprising the ebb-tidal delta will be shifted and redistributed, possibly leading to additional disruption of the natural sand bypassing process and exacerbation of downdrift erosion.

(4) Shore-connected breakwaters affect shorelines in much the same manner as jetties. Accretion occurs along the updrift junction of shore and structure and continues until longshore transport is deflected around the free end to the breakwater. Calm waters in the protected lee of the breakwater provide a depositional area which can rapidly shoal (Figure 5-7). Sediments trapped in the accretional area and terminal shoal are prevented from reaching downdrift beaches, and substantial erosion may result.

(5) Offshore breakwaters create depositional areas in their "shadows" by reflecting or dissipating wave energy. Reduction of wave energy impacting a shoreline in the lee of the structure retards the longshore transport of sediments out of the area and accretion ensues. The extent of accretion will depend on the existing balance of shore processes at a given project site. Generally, a cuspate spit will develop between the shoreline and the structure as the system approaches a new equilibrium (Figure 5-7). However, if the breakwater is situated in the littoral zone such that it forms a very



DETACHED EMERGENT BREAKWATER



ATTACHED BREAKWATER

Figure 5-7. Erosion and accretion patterns in association with detached and attached breakwaters effective sediment trap, a complete connection will eventually form, merging the shoreline with the structure. A tombolo associated with an offshore breakwater may present a severe obstruction to littoral transport and trap a significant volume of sediment. Extensive downdrift erosion may result.

(6) By modifying the cross-sectional area of an inlet, jetty construction potentially can alter the tidal prism, or volume of water entering or exiting through an inlet in one tidal cycle (usually excluding freshwater inflow). Enlarging an inlet can increase the tidal range within a harbor. In connection with channel deepening projects, seawater may intrude further into estuaries, embayments, or rivers than occurred under preproject conditions. Circulation patterns within a basin may be altered as a consequence of modified floodwater current conditions. Thus, the area physically affected by jetty construction might be extended appreciable distances from the actual project site. Conceivably, in systems with multiple connections to the sea, jetty construction at one inlet might elicit a response at a second inlet.

d. Water Quality Considerations.

(1) Suspended sediments. During the construction of a breakwater or jetty, suspended sediment concentration may be elevated in the water immediately adjacent to the operations. In many instances, however, construction will be occurring in naturally turbid estuarine or coastal waters. Plants and animals residing in these environments are generally adapted to, and are very tolerant of, high suspended sediment concentrations. The current state of knowledge concerning suspended sediment effects indicates that anticipated levels (generally less than 1,000 milligrams/l) generated by breakwater or jetty construction do not pose a significant risk to most biological resources. Limited spatial extent and temporal duration of turbidity fields associated with these construction activities reinforce this assessment. However, when construction is to occur in a clear water environment, such as in the vicinity of coral reefs or seagrass beds, precautions should be taken to minimize the amounts of resuspended sediments. Organisms in these environments are generally less tolerant to increased siltation rates, reduced levels of available light, and other effects of elevated suspended sediment concentrations. Potential negative impacts can be somewhat alleviated by erection of a floating silt curtain around the point of impact when current and wave conditions allow. However, the high-energy conditions usually associated with jetty and breakwater construction will generally preclude the use of silt curtains.

(2) Other water quality impacts. Indirect impacts on water quality may result from changes in the hydrodynamic regime. The most notable impact of this type is associated with breakwaters which form a semienclosed basin used for small boat harbors or marinas. If the flushing rate of the basin is too slow to provide adequate removal of the contaminants, toxic concentrations may result. Also, fluctuations in parameters such as salinity, temperature, dissolved oxygen, and dissolved organics may be induced by construction or due to altered circulation patterns. Anticipated changes in these parameters should

be evaluated with reference to the known ecological requirements of important biological resources in the project area.

e. Biological Considerations.

(1) Habitat losses. Measurable amounts of bottom habitat are physically eradicated in the path of fixed jetty or breakwater construction. If a rubble-mound structure with a toe-to-toe width of 50 meters (164 feet) is used as an example, one linear kilometer (0.6 mile) of structure removes approximately 5 hectares (12.5 acres) of preexisting bottom habitat. Once a structure is in place, water currents and turbulence along its base can produce a scouring action, which continually shifts the bed material. Scour holes may develop, particularly at the ends of structures. Scouring action may effectively prevent the colonization and utilization of that habitat area by sediment-dwelling organisms. Effects of scouring are largely confined to entrance channels and narrow strips of bottom habitat immediately adjacent to structures. Usually, only a portion of the perimeter of a structure will be subject to scouring, such as along the channel side of an inlet’s downdrift jetty. Generally, the amount of soft bottom habitat lost at a given project site will be insignificant in comparison with the total amount of that habitat available. Exceptions to this statement may exist, such as where breakwater construction and dredging of the total enclosed harbor area will displace large acreages of intertidal mudflats. Often such habitats serve critical functions as nursery areas for estuarine-dependent juvenile stages of fishes and shellfishes, and the availability of those habitats will be a determining factor in the population dynamics of these species. Additional habitat losses may occur when significant erosion of downdrift shorelines impact spawning or nesting habitats of fishes, shorebirds, or other organisms and when the tidal range of a harbor or bay is modified by entrance channel modification which in turn affects coastal habitat. Short-term impacts of this type may also occur during construction activities as heavy equipment gains access to the project site.

(2) Habitat gains.

(a) Losses of benthic (bottom) habitat and associated benthos (bottom-dwelling organisms) due to physical eradication or scouring will gradually be offset by the gain of new habitat represented by the structures themselves and the biological community, which becomes established thereon. The trade-off made in replacing "soft" (mud or sand) bottom habitat with "hard" (rock, at least in rubble-mound structures) bottom habitat has generally been viewed as a beneficial impact associated with jetty and breakwater projects. Submerged portions of jetties and breakwaters, including intertidal segments of coastal structures, function as artificial reef habitats and are rapidly colonized by opportunistic aquatic organisms. Over the course of time, structures in marine, estuarine, and most freshwater environments develop diverse, productive, reeflike communities. Detailed descriptions of the biota colonizing rubble-mound structures have been made for project sites on the Pacific (Johnson and De Wit 1978), Atlantic (Van Dolah et al. 1984), Gulf of Mexico (Hastings 1979, Whitten et al. 1950), and Great Lakes (Manny et al. 1985) coastlines.

In some geographical areas jetties and breakwaters provide the only nearshore source of hard-bottom habitat. Also, exposed portions of detached structures may be colonized by seabirds.

(b) The ultimate character of the biological community found on a jetty or breakwater will depend on the quality of habitat afforded by the construction materials used. Physical complexity (i.e., rough surfaces with many interstitial spaces and a high surface area to volume ratio) is a desirable feature of rubble-mound structures in comparison with the relatively smooth, flat surface of steel sheet pile or caisson structures. The sloping sides of rubble-mound structures also maximize the surface area of habitat created. Structures with sloping sides also provide more habitat within a given depth interval than structures with vertical elements. Where depths are sufficient, the biota on jetties and breakwaters exhibit vertical zonation, with different assemblages of organisms having discrete depth distributions. In general then, structures built in deep waters will support a more diverse flora and fauna than those in shallow waters. This pattern will be influenced by such factors as latitude and tidal range.

(c) Just as changes in shoreline configuration and beach profile can entail habitat loss, so can they represent habitat gain. Accretional areas, such as cuspate spits, tombolos, and exposed bars, and the above water portion of structures may be used, for example, by wading and shorebirds for nesting, feeding, and resting sites.

(3) Migration of fishes and shellfishes.

(a) Eggs and larvae. Early life history stages, namely eggs and larvae, of many important commercial and sport fishes and shellfishes are almost entirely dependent on water currents for transportation between offshore spawning grounds and estuarine nursery areas, A concern which has sometimes been voiced by resource agencies in relation to jetty projects is that altered patterns of water flow through coastal inlets may adversely affect the transport of eggs and larvae. Jetties displace the entrance to an inlet to deeper waters, perhaps forming a barrier to successful entry by eggs and larvae. Those eggs and larvae carried by longshore currents might be especially susceptible to entrapment or delay in eddies and slack areas formed adjacent to updrift jetties at various times in the tidal cycle. Even short delays in the passage of eggs and larvae to estuaries may be significant because of critical relationships between the developmental stage when feeding begins and the availability of their food items. All aspects of this potential impact remain hypothetical. Mechanisms of egg and larval transport across shelf waters and through inlets, as well as their retention within estuaries, have not been explained to date. No conclusive evidence exists to support either the presence or absence of impacts on egg and larval transport. This fact is true even where jettied inlets have been present for relatively long spans of time, such as along the Texas coast. The complexity of the physical and biological processes involved would render field assessments of this impact a long-term and expensive undertaking. Even if some degree of impacts in terms of numbers of eggs and larvae successfully transiting an inlet could be demonstrated to occur, the relative significance of the impact would be difficult to estimate. The results of hydraulic modeling studies related to this question have been inconclusive (US Army Corps of Engineers 1980). Future modeling studies combined with field verification studies may provide insight into resolving the validity of this concern.

(b) Juveniles and adults. Similar concern has been voiced regarding potential impacts of jetties and breakwaters on migrations of juvenile and adult fishes and shellfishes. These stages generally have well-developed swimming capabilities, such that physical barriers imposed by these structures are less of a concern than are behavioral barriers. This issue has been raised primarily in association with projects in the Pacific Northwest, and with anadromous fishes in particular. Anadromous fishes, including many salmonids, spend much of their adult life in the ocean, then return to fresh water to spawn. Early life history stages spend various lengths of time in fresh water before moving downstream to estuaries where the transition to the juvenile stage is completed. Specific concerns are that juveniles or adults will not circumvent structures that extend for considerable distances offshore. Juveniles in particular are known to migrate in narrow corridors of shallow water along coastlines and may be reluctant, due to depth preferences, to move into deeper waters. The State of Washington has developed criteria, whereby continuous structures that extend beyond mean low water (MLW) are prohibited. Designs of coastal structures there are required to incorporate breaches or gaps to accommodate fish passage.

(4) Increase predation pressure. Coastal rubble-mound structures provide substrate for the establishment of artificial reef communities. As such, jetties and breakwaters serve as a focal point for congregations of fishes and shellfishes which feed on sources of food or find shelter there. Many large predator species are among those attracted to the structures in numbers, as evidenced by the popularity of jetties and breakwaters as sites of intense sport fishing. Thus, there is concern, again largely associated with projects in the Pacific Northwest, that high densities of predators in the vicinity of jetties and breakwaters pose a threat to egg, larval, and juvenile stages of important species. For example, fry and smolt stages of several species of salmon are known to congregate in small boat harbors prior to moving to the sea. The concern raised is that these young fishes are exposed to numerous predators during their residence near the structures. As is the case with the concern for impacts on migration patterns, this concern remains a hypothetical one. Conclusive evidence demonstrating the presence or absence of a significant impact is unavailable and will be exceedingly difficult to obtain.

f. Recreational Considerations. The primary impact of breakwaters on recreational use of the beach depends largely upon the type of use the beach receives. Breakwaters reduce nearshore wave climate, which is generally beneficial to swimming, scuba diving, and wading activities. They may also cause a widening of the beach, which can result in increased recreational area. Figure 5-8 illustrates a wide beach accreted adjacent to a breakwater. Ownership of accreted beaches is determined by state law unless agreements are otherwise entered into prior to construction of the project. Diminished waves

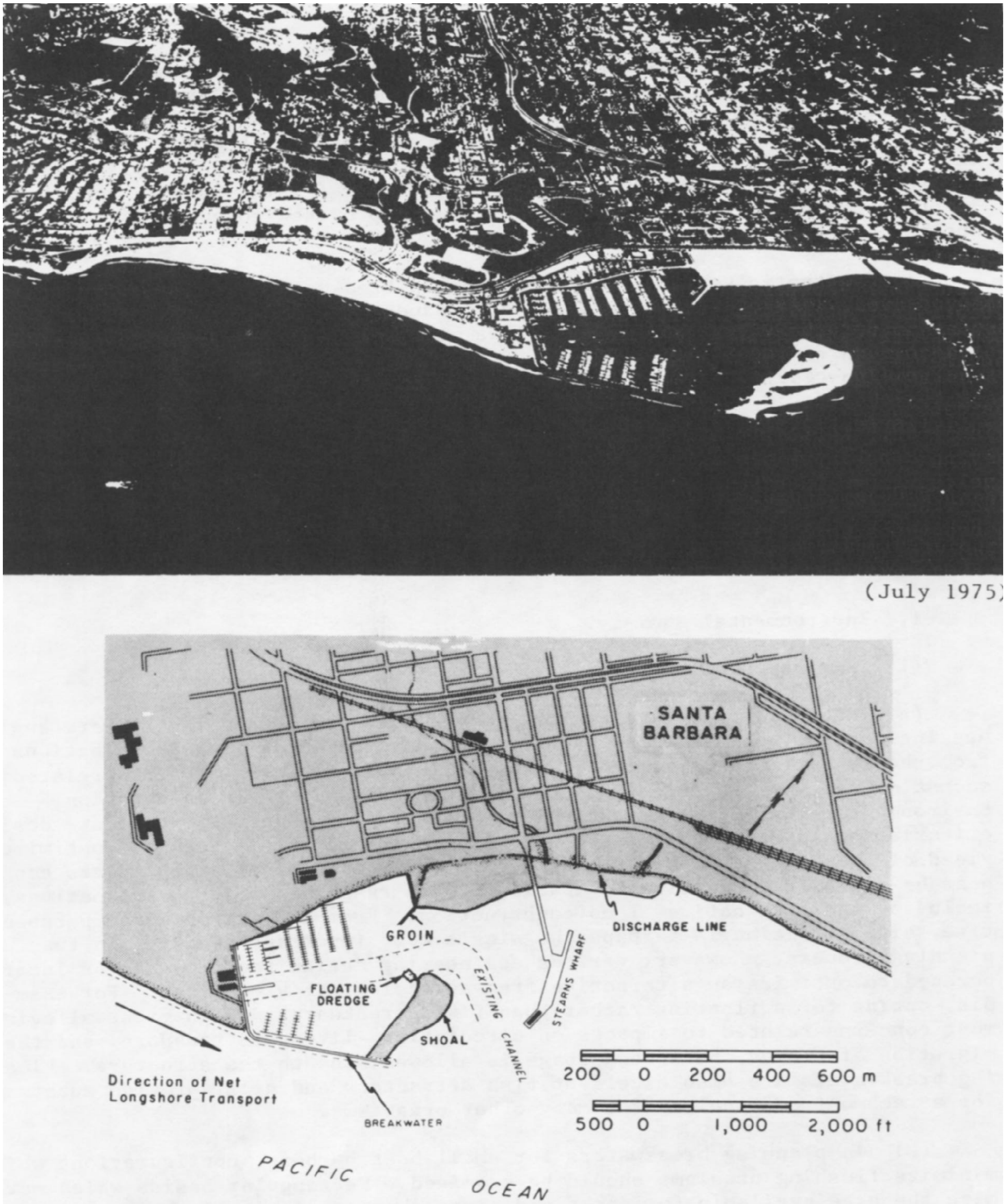


Figure 5-8. Breakwater protecting recreational harbor,
Santa Barbara, California

will, however, reduce opportunities for body or board surfing activities. Special interest groups such as surfers may therefore vocally oppose detached breakwater projects. When breakwaters are used to shelter harbors or jetties are used to stabilize inlets, they benefit recreational boating (Figure 5-8). They may also act as fish attractors and may be used as fishing platforms. However, for safety reasons access to jetties for fishing is often prohibited. In other projects, walkways and handrails are provided to enhance fishing opportunities on these structures.

g. Aesthetic Considerations. Detached breakwaters are usually far enough from the beach that they do not produce visual impacts (Cole 1974). Jetties will visually alter shore views. The texture and shape of the jetty in relation to the overall shoreline scene should be considered in jetty design (Snow 1973).

h. Cultural Considerations. By reducing shore erosion or stabilizing inlet location, breakwaters and jetties will, generally, preserve onsite cultural resources. However, this local protection can potentially increase the rate of erosion on adjacent shorelines. For this reason, cultural resources in the adjacent impact area must also be evaluated. Lighthouses and other historically important structures are often found in close proximity to inlets.

i. Environmental Summary.

(1) Environmental design.

(a) Every jetty or breakwater project scenario should incorporate engineering design, economic cost-benefit, and environmental impact evaluations from the inception of planning stages. All three elements are interrelated to such a degree that efficient project planning demands their integration. Environmental considerations should not be an after thought. Structure design criteria should seek to minimize negative environmental impacts and optimize yield of suitable habitat for biological resources. Minimizing impacts can best be achieved by critical comparisons of a range of project alternatives, including the alternative of no construction. From an environmental perspective, site selection is perhaps the single most important decision in the planning process. However, various engineering design features can be incorporated to optimize an alternative from an ecological viewpoint. For example, opting for a floating rather than fixed breakwater design might alleviate most concerns related to impacts on circulation, littoral transport, and the migration of fishes, because passage is allowed beneath the structure. Floating breakwaters are also excellent fish attractors and still provide substrate for attachment and shelter for many other organisms.

(b) In planning breakwaters for small boat harbors, configurations which minimize flushing problems should be examined. Rectangular basins which maximize the area available for docks and piers characteristically have poor water circulation, particularly in the angular corner areas. Designs with rounded corners and entrance channels located so that flood tidal jets provide adequate mixing throughout the basin are desirable. Selection of a less steep rubble-mound sideslope angle will maximize the availability of intertidal and subtidal habitat surface areas. The size class of stone used in armor layers of rubble-mound structures is another engineering design feature that has habitat value consequences. Selection of large-size material results in a heterogeneous array of interstitial spaces on the finished structure. Heterogeneity rather than uniformity enhances the quality of the structure in terms of refuge and shelter sites for diverse assemblages of fishes and shellfishes.

(2) Environmental assessment.

(a) Short-term impacts. Actual construction activities for jetties and breakwaters entail a number of potential impacts of durations generally less than several days or weeks. These impacts will vary in type and frequency from project to project. For example, temporary or permanent access roads may have to be built to allow transportation of heavy equipment and construction materials to the site. Grading, excavating, backfilling, and dredging operations will generate short-term episodes of noise and air pollution and may locally disturb wildlife such as nesting or feeding shorebirds. Project activities should be scheduled to minimize disturbances to waterfowl, spawning fishes and shellfishes, nesting sea turtles, and other biological resources at the project site. Precautions should also be taken to reduce the possibility of accidental spills or leakages of chemicals, fuels, or toxic substances during construction activities. Effort should be expended to minimize the production and release of high concentrations of suspended sediments, especially where and when sensitive biological resources such as corals or seagrasses could be exposed to turbidity plumes and increased siltation rates. Dredging of channels in conjunction with jetty or breakwater projects presents a need for additional consideration of short-term impacts in relation to suspended sediments.

(b) Long-term impacts. Long-term impacts of jetty or breakwater construction are less definitive or predictable. Ultimate nearfield effects on littoral sediment transport can be expected to become evident within several seasonal cycles. These effects will vary according to a given project’s environmental setting and specific engineering design. For example, periodic maintenance dredging will be required for catch basins adjacent to weir jetties. Consequences of constructing coastal structures on farfield shore processes are presently understood only qualitatively.

5-3. Groins.

a. General.

(1) Groins are barrier-type structures that extend from the backshore into the littoral zone. Although single groins are constructed on occasion, groins are generally constructed in series, referred to as a groin field or system, along the entire length of beach to be protected.

(2) Groins have been constructed in various configurations which are classified as high or low, long or short, permeable or impermeable, and fixed or adjustable. A high groin, extending through the surf zone for ordinary or moderate storm waves, initially entraps nearly all of the longshore moving sand within that intercepted area, until the accumulated sand fills the entrapment area and the sand passes around the seaward end of the groin to the downdrift beach. Low groins (top profile no higher than that of desired beach dimensions or natural beach elevation) trap sand like high groins. However, some of the sand also passes over the top of the structures. Permeable groins permit some of the wave energy and movement of sand through the structure.

(3) A number of factors are taken into consideration in the design of groins. As with other coastal structures, the prevailing wave climate at a project site is of paramount importance. Wave energies and the angle of wave approach onto a beach are critical factors in predicting the response of a shoreline to groin construction. The direction and rate of littoral drift will also determine design specifications. Additional factors include the existing pattern of water currents and the spatial distribution of accretional and depositional areas. These factors are essentially identical to those considered in the previous section on jetties and breakwaters. Indeed, the major differences between groins and these structures are in terms of function rather than form. In general, groins are smaller, less massive structures than jetties or breakwaters. An example of rubble-mound groin design is depicted in Figure 5-9. The length or seaward extent of a groin will largely determine the initial effectiveness of the structure as a barrier to littoral transport, so that the design length will vary from project to project. In most cases, a groin will be built out to the distance at which incoming waves exert their maximum force on bottom sediments. The length of a groin will determine the ultimate rate of sediment passage around the end of the structures (end passing), whereas the design height of the groin will largely determine the rate of sediment movement over the structure (overpassing). Overpassing can be augmented by incorporation of one or more weir sections into the groin or groin field design. The shoreward terminus of a groin is generally set sufficiently far inshore that abnormally high tides will not flank the structure, thereby preventing possible scouring, undercutting, and failure.

(4) As in the case of jetties and breakwaters, a wide variety of materials are used in the construction of groins. Impermeable groins can be constructed of stone (rubble-mound), sheet piles (concrete, timber, or steel), or asphalt. Often these materials are used in combination; for example, concrete may be set as a grout or cap in rubble-mound groins. In addition to the above materials, permeable groins can be made of sand bags, large stones, and earth, or by slots created in sheet-pile structures, although these are not commonly employed. Selection of construction materials depends on foundation characteristics of the seabed as well as cost and availability factors.

b. Role in Shore Protection. The basic purpose of groins is to modify the longshore movement of sand and to either accumulate sand on the shore or retard sand losses. Trapping of sand by a groin is done at the expense of the adjacent downdrift shore unless the groin or groin system is artificially

Westhampton Beach, New York (1972)

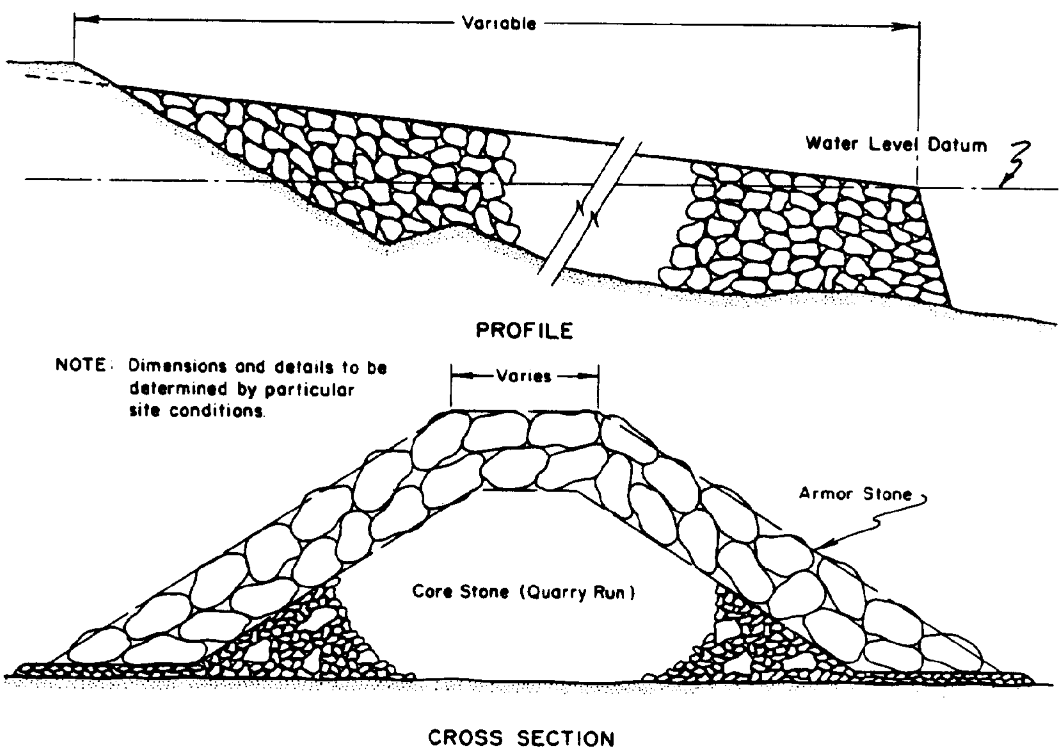


Figure 5-9. Rubble-mound groin

filled with sand to its entrapment capacity from other sources. To reduce the potential for damage to property downdrift of a groin, some limitation must be imposed on the amount of sand permitted to be impounded on the updrift side. It is desirable, and frequently necessary, to place sand artificially to fill the area between the groins, thereby ensuring an uninterrupted passage of the sand to the downdrift beaches. When fill is used, the groin functions to anchor the fill material. In either instance, groins provide shore protection by modifying longshore sand transport.

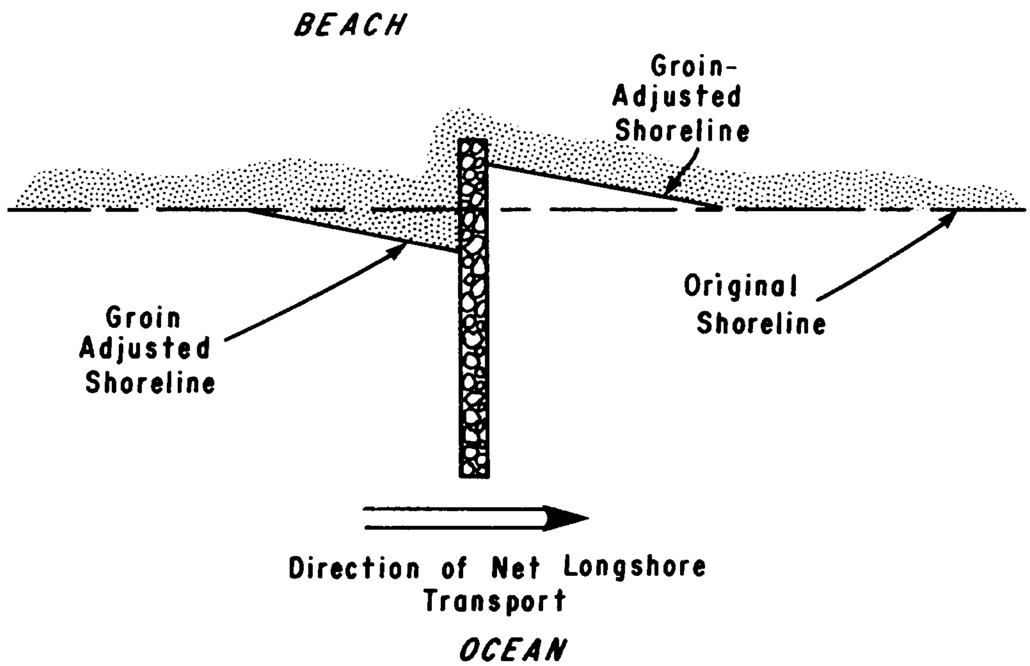
c. Physical Considerations.

(1) The effects of groins on shore processes are very similar to those discussed in reference to jetties and breakwaters. Groin construction will initially disturb the balance or equilibrium between physical processes at a given project site. With the passage of time, the system will tend to develop some new set of equilibrium conditions. The reader is referred to the discussion of physical impacts in the preceding section on jetties and breakwaters.

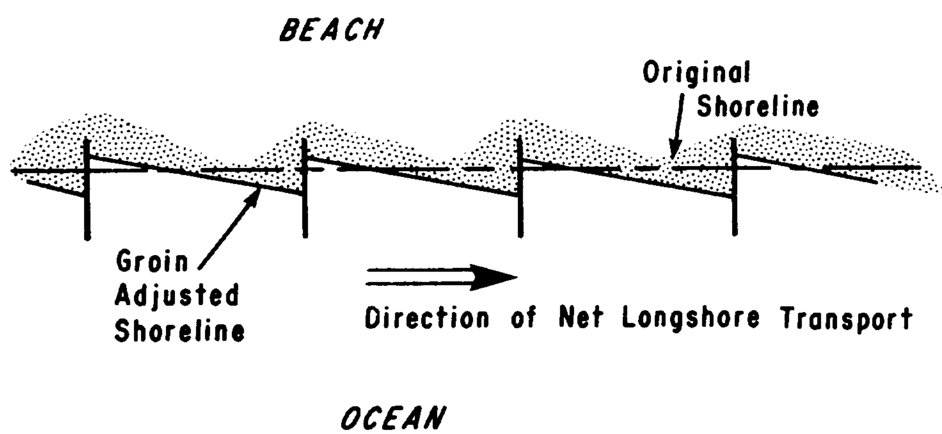
(2) By creating a barrier to littoral transport, groins cause changes in both shorelines and beach profiles. Entrapment of littoral drift results in the gradual buildup of a fillet on the updrift side of a groin. The fillet will grow until the volume of the available sediment sink reaches capacity and the rate of littoral drift is accommodated by endpassing or overpassing of the structure. Accretion of the updrift beach also shifts the location of the breaker zone offshore. Downdrift shorelines, however, will be deprived of that volume of sand accreted updrift of the groin and become susceptible to erosion. The overall displacement of both updrift and downdrift shorelines will reflect the groin's relative effectiveness as an obstruction to littoral transport (Figure 5-10). In turn, effectiveness as a transport barrier will largely be determined by the orientation of the groin to the direction of approaching waves. Adjustment of the shorelines within the influence of a groin or groin field will tend toward achieving normality, i.e., shorelines perpendicular to the direction of wave approach. Net littoral longshore transport is reduced to zero when waves move onto shore in a normal or perpendicular manner, thus expending their energy equally in both lateral directions.

(3) Changes in beach profiles in response to groin construction can be substantial. Growth of the updrift fillet alters the locations and slopes of the foreshore and nearshore zones. The alteration may also cause selective settlement of sediments of different size categories along the beach profile and result in graded rather than uniform substrate conditions.

(4) Groins may interfere with the onshore-offshore transport process by displacing the position of longshore currents and rip currents. Rip currents within groin compartments (the area between two consecutive groins in a groin field) may displace sediments from the shallow beach areas, carry them by jetting action, and deposit them in deeper offshore areas, thus preventing them from being carried to downdrift sections of the beach. Rip currents can be generated as the longshore movement



a. Single groin



b. Multiple groins

Figure 5-10. General shoreline changes associated with single or multiple groins of water is deflected seaward by the presence of a groin.

d. Water Quality Considerations.

(1) Groin construction operations may induce short-term episodes of elevated suspended sediment concentrations in the water column. This impact will usually be limited to the water immediately adjacent to the structure. Historically, concerns have been raised in connection with potential detrimental impacts of high suspended sediment loads on biological resources. However, the present state of knowledge on this topic allows an assessment that concentrations of suspended sediments found at groin construction projects pose minimal risk to lost flora and fauna likely to occur at these sites. Most estuarine and coastal marine organisms are highly tolerant to elevated suspended sediment concentrations for moderate to extended periods of time. As was stated in the discussion relevant to jetties and breakwaters, however, precautions such as the installation of silt curtains should be considered when feasible, where sensitive resources such as coral reefs and seagrass beds are located in the vicinity of a project.

(2) Because groins change local patterns of water circulation, sane changes in water quality parameters may also be anticipated. Slight fluctuations in temperature, dissolved oxygen, and dissolved organics may occur in the sheltered waters in the lee of groins. These impacts should be insignificant for most groin project scenarios.

e. Biological Considerations.

(1) Habitat alterations, both losses and gains, associated with groin construction projects are analogous to those discussed for jetty and breakwater projects. Because groins are generally smaller structures by comparison, these habitat changes are usually on a smaller scale. Construction operations will physically displace existing bottom habitat covered by the placement of structural materials, particularly in the case of rubble-mound groins. This habitat loss will be supplemented by scouring effects of water movement along the base of the structures. The amounts of bottom habitat involved will be dependent upon the number, location, and size of groins in relation to the total available habitat. Exceptional cases, such as tidal flats, do exist and should be examined on a project by project basis. Initial bottom habitat losses are later offset at least in part by the habitat represented by the structures themselves. Often the local diversity of bottom habitats, including the presence of scour holes, will be enhanced by groin construction. Where scouring effects would represent unacceptable habitat loss, they can be minimized by proper design of the groin, for example, by inclusion of a weir section.

(2) Habitat gains are evidenced by the biota which becomes established upon groin structures, although due to the shallow nature of groins, these biological communities are somewhat less diverse than those on larger jetties and breakwaters built of similar materials. Nevertheless, groins provide

substrate which serves as artificial reef habitat in the nearshore zone. Rubble--mound groins especially afford a physically complex habitat in support of productive invertebrate and fish assemblages.

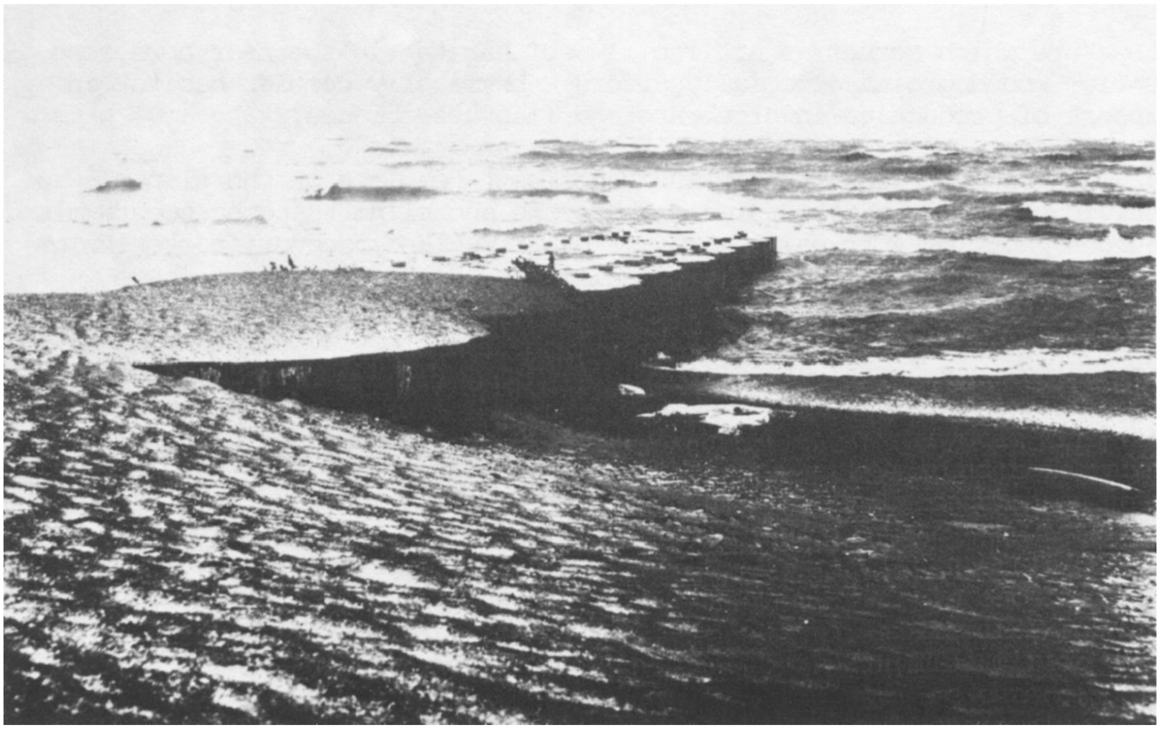
(3) Habitat losses and gains can also take place on shorelines influenced by groin structures. Where the shoreline response occurs along the periphery of a fringing marsh or other wetland, downdrift erosion or updrift accretion can result in significant adverse impacts. These impacts must be weighed against the eventual habitat losses incurred if stabilization by groins or other alternatives is not accomplished. Groin associated accretional areas may provide substrate for the establishment of beach vegetation. Shoreline responses to groins may also represent loss or gain of wildlife or fishery habitat in the form of nesting, spawning, nursery, resting, feeding, or shelter areas.

(4) Small groins have not been documented or implicated to have effects on the movements or migration patterns of fishes and shellfishes. Groins are very effective fish attractors and provide excellent sport fishing sites. Predation effects, as discussed under the biological impacts of jetties and breakwaters, have not been a significant topic of concern in relation to groin projects. These structures, particularly those of rubble-mound construction, may provide beneficial protective cover, as well as feeding and resting areas for both juvenile and adult fishes and shellfishes during coastal migrations.

f. Recreational Considerations. By increasing beach width, groins increase beach area available for use. However, they can be a safety hazard to nearshore recreation activities such as swimming, wind surfing, board surfing, and shallow-water diving. Potentially dangerous conditions can be created where the waves first encounter the structure or where rip currents are created between groins. Scour holes adjacent to groins also constitute safety hazards to nonswimmers. Also, some groin structures may impede lateral movement of beach users.

g. Aesthetic Considerations. One common feature of natural beaches is the presence of long, straight stretches of sand. Groin fields usually alter beach topography into a series of abrupt indentations (Figure 5-10). In addition, the materials used to construct groins and their linear configuration substantially alter the scenic character of the beach (Figure 5-11).

h. Cultural Considerations. Groins can protect onsite cultural resources by reducing shore erosion. However, the downdrift erosion usually associated with groins can potentially threaten cultural resources in adjacent areas. For this reason, cultural resource losses in the adjacent impact areas must also be considered. Cultural resource surveys should be conducted prior to construction. Placement of groins should accommodate cultural resource protection in so far as practical, while accomplishing the primary purpose of the project.



Presque Isle, Pennsylvania (Oct. 1965)

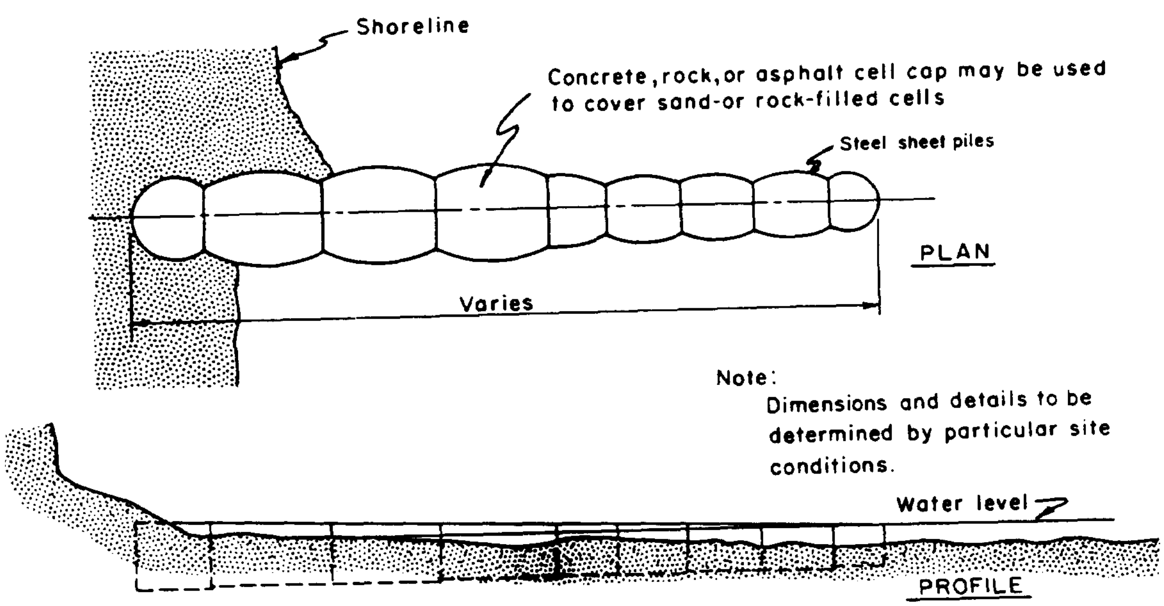


Figure 5-11. Irregular beach formed by cellular steel sheet-pile groin

i. Environmental Summary.

(1) Environmental design. Downdrift erosion will often be an important environmental consideration. Downdrift erosion can be ameliorated by providing beach fill, reducing groin height (overpassing) and length (endpassing), or incorporating permeability. The selection of construction materials can also be important to the overall impact of the project. Because rubble-mound structures provide a variety of living spaces and a firm surface for attachment, they are often considered beneficial habitats.

(2) Environment assessment.

(a) Short-term impacts. Construction operations are a source of several types of short-term impacts. Transportation of construction materials and operation of heavy equipment at the project site will generate localized incidences of air and noise pollution. Flexibility in the scheduling of these activities should be exercised to minimize disturbance of coastal biological resources, especially during critical spawning and nesting periods. Short-term events of elevated turbidity induced by groin construction or associated beach fill will occur. As discussed under water quality impacts, proper precautions should be taken to reduce suspended sediment effects if sensitive organisms or habitats are present.

(b) Long-term impacts. Long-term impacts of groin construction, as for jetty and breakwater construction, are difficult to assess. Downdrift erosional problems are by far the major topic of concern, and these will vary in magnitude among different projects. Deprivation of downdrift shorelines appears to be a cumulative impact in that large groin fields may take extended periods to attain their sediment entrapment capacities. Therefore, the downdrift erosional process, if not mitigated by nourishment or sand bypassing, could be both severe and prolonged. Such erosion may produce recreational impacts (loss of downdrift beach area), cultural resource impacts (erosion of cultural sites), and biological impacts (erosion of biologically productive habitats).